Acoustic Communications for UUVs

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LONG-TERM GOAL

The use of Unmanned Undersea Vehicles (UUVs) as off-board sensor platforms for complex missions such as MCM reconnaissance requires an acoustic communication link for command and control as well as mission data product upload. The communications link needs to be robust and useful in a number of different scenarios. These scenarios include a variety of frequency regimes and a number of different sized vehicles with different capabilities. However, there is a continuum of performance regions that are possible given a certain investment in transducer and array hardware on the vehicle. Based on a balance between mission requirements and UUV cost the proper system may be designed. Ultimately, the acoustic communication link will be an ubiquitous part of every underwater vehicle, for the present we are exploring the level of performance available with practical technology available at this point in time.

OBJECTIVE

The objective of this program is the design, development and testing of a bidirectional acoustic communication system for use on the Florida Atlantic University (FAU) Ocean Explorer vehicle in conjunction with the Acoustic Communication (ACOMMS) Advanced Technology Demonstration (ATD). In particular, the final objective is to operate the vehicle at sea with the USS ASHEVILLE during the final test of the high-frequency portion of the ACOMMS ATD.

Additional objectives for the program include determination of practical transmit and receiver size and placement on a small UUV as well as the estimation of the impact of such constraints on UUV communication system performance.

APPROACH

The installation and test of the acoustic communication system has included consideration of a number of different issues. These issues include:

- Self-noise of the vehicle including spatial and frequency dependence of the noise field.

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- Vertical and horizontal aperture available for the receiver on the vehicle.

- Structural considerations (i.e. UUV material and location of air-filled bodies) which impact the placement of sources within, on or outside shell of the UUV.

- Efficient transfer of large files using high data rates while maintaining high reliability for downlink command and control or vehicle status uplink.

WORK COMPLETED

A. UUV Hardware

The first item of work that was performed under this program was a complete characterization of Ocean Explorer vehicle self-noise. These tests were performed at the acoustic test facility at NUWC. The work was considered an essential part of the design process because it would allow the best selection of frequencies and transducers in order to meet the goals of the program.

Two frequency regimes were used, a medium-frequency (MF) band between 2-4 kHz and a high-frequency (HF) band centered near 25 kHz. In order to maintain compatibility with the ATD systems it was deemed desirable to install and test bidirectional modem capability at both of these frequencies.

Results of the self-noise study are shown in Fig. 1. The vehicle noise at the lower frequency (around 3 kHz) is very high, many dB above the expected ambient level. This means that it will be extremely difficult for the vehicle to receive signals in that band with an array mounted on the vehicle. However, in the 25 kHz band the noise drops off significantly and though there is still noise above the expected ambient level, installation of the HF receiver in or on the UUV is feasible.

The second test which was performed on the AUV was insertion loss and beampattern for both frequencies. At the lower frequency the loss through the vehicle's free-flooded shell is low, less than 1-2dB. Regarding placement of the MF projector, commonsense dictated that it be located as far away as possible from battery and electronics pressure cases. Indeed, when located in the nose of the vehicle reasonable coverage was obtained due to the relatively long wavelength of the signals at this frequency.

While the MF projector could be installed within the outer shell in order to minimize drag, the HF transducers, both transmit and receive, could not be placed within the shell due to the high insertion loss through the fiberglass shell. Thus the HF projector and receiver are placed outside the vehicle on the top of the forward payload section.

The size of the arrays was governed by the desired directivity (and thus efficiency) for the projector, and the selected projector is approximately six inches tall providing a +/- 12 degree beampattern with a transmit voltage response of 139 dB (***). The receive array is slightly larger, about eight inches tall and containing 6 elements spaced one inch apart. The vertical size is a compromise between drag produced by the position of the array and the multipath rejection that is

possible with the vertical aperture. Vertical arrays provide excellent performance for coherent communications systems in most underwater environments where multipath spans a relatively narrow angle. As shown in Fig. 2, the two HF arrays are positioned within a streamlined flow shield which reduces drag and protects them from damage.

While the HF transducers are placed on the structure and the MF projector is located within the shell, the MF receiver must be removed from the vehicle by at least 30 meters in order to reduce the noise generated by the propulsion system. An array with a 30 meter separation from the vehicle to the first element is towed behind the vehicle and eight elements spaced 1 m apart are used to provide a measure of spatial diversity. While the array complicates handling the vehicle and adds additional drag, the top speed of the vehicle was typically reduced by only one-half knot when the array was used.

The other major item of hardware which makes up the modem is the electronics system installed on the vehicle. The unit is a standard WHOI PC modem augmented by dual analog front-ends and a multiplexer which allows use of either receive array. In order to efficiently drive the two different sources there are two power amplifiers configured appropriately for the impedance and voltage drive level of each source.

B. UUV Modem Software

The software designed for use on the modem includes two major modes of operation. The first is for use in maximizing the reliability of the vehicle control through use of two low-rate, high-redundancy encoding, data packets. While the vehicle modem can in fact use many different bit rates, the lowest rate is generally reserved for sending commands to the vehicle. In order to provide maximum flexibility the modem is capable of determining the rate of a particular packet as it is received, avoiding the requirement of a 'hand-shaking' period which requires several transactions in order to set up the bit rate. The burst data rates within a packet including error-correction coding vary from about 6600 bits per second (QPSK at 5000 symbols per second with high-rate coding at HF) all the way down to about 150 bits per second (BPSK at 1250 symbols per second with low-rate coding at MF). The variable rates allow efficient transfer of larger data products generated on the vehicle, while also ensuring that smaller unit can process the data in real-time.

The high reliability of the low-rate packets is achieved through use of high-gain, error-control coding coupled with a modified decision feedback equalizer (DFE) which allows the gain to be exploited prior to generation of the error signal which is fed back to control the adaptation of the filter taps. This technique was developed for use at either low signal to noise ratios (i.e. at long ranges), or in very severe reverberation where the equalizer is unable to remove all of the inter-symbol interference.

C. Data Compression and Transfer

The efficiency of the link during transfer of large files is maintained through use of the highest rate (roughly 6600 bps with ECC, 10000 bps as uncoded QPSK) most of the time. However, use of the high rate means that inevitably some packets will be list during the transfer process. Thus the information in each packet is encoded to be stand-alone at the receiver and immediately useful to

the operator. In the case of image transfer this is accomplished by breaking up the picture into blocks whose size in pixels is determined by the amount of information in a particular block. Each of the variable-sized blocks is thus compressed into the same packet size (approximately 1 kbyte), though the actual size of the image within the packet is determined by its degree of compressibility. The fact that each packet is atomic means that as the data is received by the host vessel the individual packets are decoded and decompressed, then displayed for observers.

The final component of the modem is the protocol necessary to take care of retransmission of packets which are received with errors even after the error correction is applied. This is accomplished using a very simple automatic repeat request (ARQ) protocol. The ARQ systems works as follows: first the vehicle prepares the data by adaptively compressing an image to some number of identical-size packets as described above; the packets are transmitted using high-rate QPSK. After the transmitter is finished it wait for feedback from the receiver. At the host each packet is decoded and displayed if it is correct, or added to a list of bad packets if it contains errors. After all images have been transmitted the receiver sends a request for the bad packets to be transmitted again. The low-rate coding method is used in order to reduce the likelihood that this control packet will itself have errors and complicate the transfer. The process of re-requesting bad packets can continue until the operator has all the data.

Since the transmission process can be lengthly, the modem is programmed to send low-rate status packets with vehicle health information at regular intervals within the sequence of image packets. At the receiver these packets are automatically recognized, decoded and then routed to the vehicle status display.

RESULTS

The various capabilities of the vehicle communication system were tested at a number of different venues, including the Gould Island test range in Newport, coastal Florida and the Berry Islands in the Bahamas. During these tests the modem was tested at both frequencies and in both directions, transmit and receive, at all of the data rates described above. The tests in Florida and the Berry Islands are further described in Proc. Oceans 98.

The final demonstration was performed in the Hawaiian Islands in two locations, one in shallow-water off Lanai, the othe in open water southeast of Penguin Bank approximately 80 miles from Oahu. The tests were conducted with the R/V Moana Wave as the UUV tender and the USS ASHEVILLE as the communications host.

The acoustic modem on the ASHEVILLE utilizes the High Frequency (HF) sonar system via a custom beamload for the array and a direct interface to the ATD VME-based modem. A 'back-end' for packet management and image decompression was installed on a separate workstation for use during the trials. The test was performed over a five day period with vehicle operations conducted during the day and nights used for throughput and range testing from the MOANA WAVE to the USS ASHEVILLE. During the tests the USS ASHEVILLE generally kept the vehicle within about 2000 m though occasionally the range did increase to 4000 m during manuevers or turns.

An example of the vehicle status display is shown in Fig. 3. The AUV dead-reckoned position plus various sensors are plotted for the operator. At the bottom is the vehicle battery voltage which was important because the vehicle was programmed to automatically end the mission when it dropped below a certain level. This allowed maximizing the total mission time without concern about damaging the batteries by over-extending them.

An example of an image transmitted by the vehicle and received by the USS ASHEVILLE during the test is shown in Fig. 4. This image is a sidescan mosaic taken from a survey performed by the WHOI deep submergence group which was selected as an example of a large mission data product that might be produced on-the-fly by vehicles of the future. The varying data block sizes are visible, demonstrating the adaptive compression which was used to ensure uniform quality of the image while maximizing the number of original pixels in a packet.

A failure in the analog front-end on the vehicle modem prevented the downlink from being used during this test. Thus no control or ARQ was actually demonstrated using the USS ASHEVILLE.

IMPACT/APPLICATIONS

The May 1999 demonstration provided a viable high data rate acoustic communication link between an AUV offboard sensor and a submarine. Over a megabyte of raw data, compressed to forty packets as shown in Figure 4, were successfully transferred to the submarine to illustrate the download a mission data package. This evolution was repeated several times in different environmental scenarios where the download was successful. The host control link to the UUV was not operational due to system failure on the AUV receiver for the May test. However, the host control link was demonstrated successfully in the work up testing in the Berry Islands, Bahamas. The sensor download demonstration shows the capability of acoustic high data rate link in providing the host platform substantial sensor data and extending the sensors from the host platform.

TRANSITION

We are supporting the Navy UUV Program Office PMS403 in the technology risk mitigation of acoustic communication technology for use in future Navy UUV developments. The technology will be presented to prime contractor(s) in technology exchanges for potential future upgrades.

RELATED PROJECTS

A related project started this year at WHOI is the ONR MCM effort which is focussed on shallow-water communication with AUVs. A number of the developments of the ATD vehicle communication effort have been applied to this program though the water depths of interest are very shallow: 10 to 40 feet.

REFERENCES

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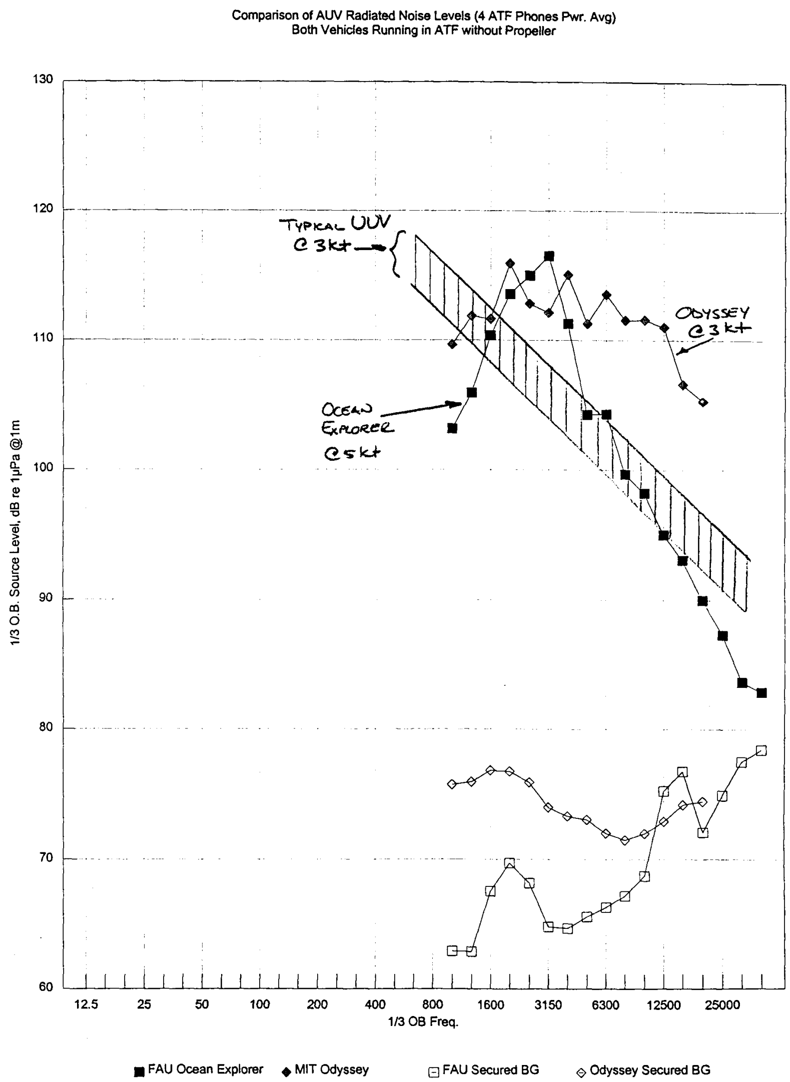
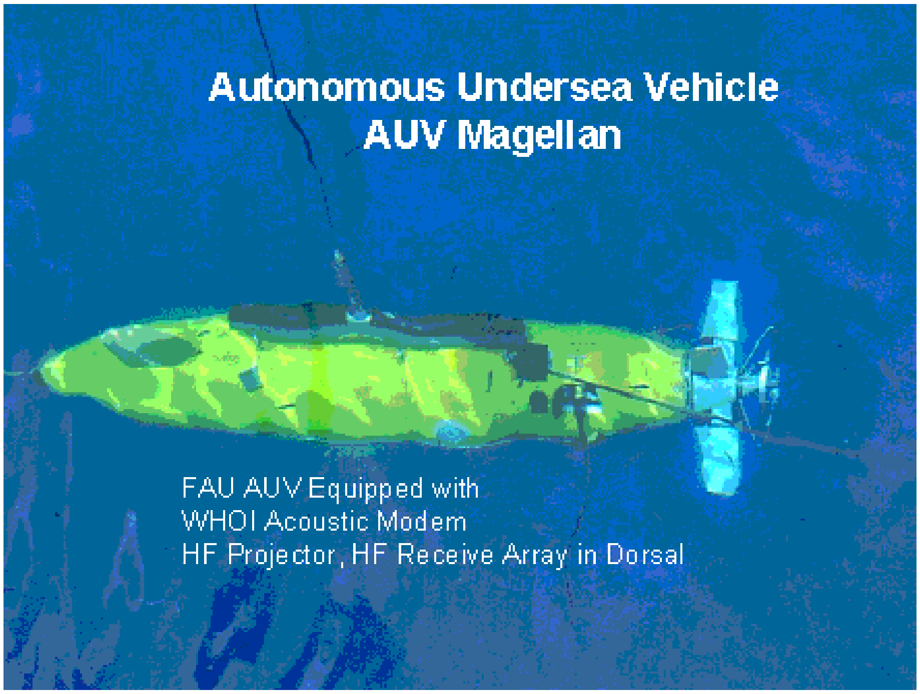
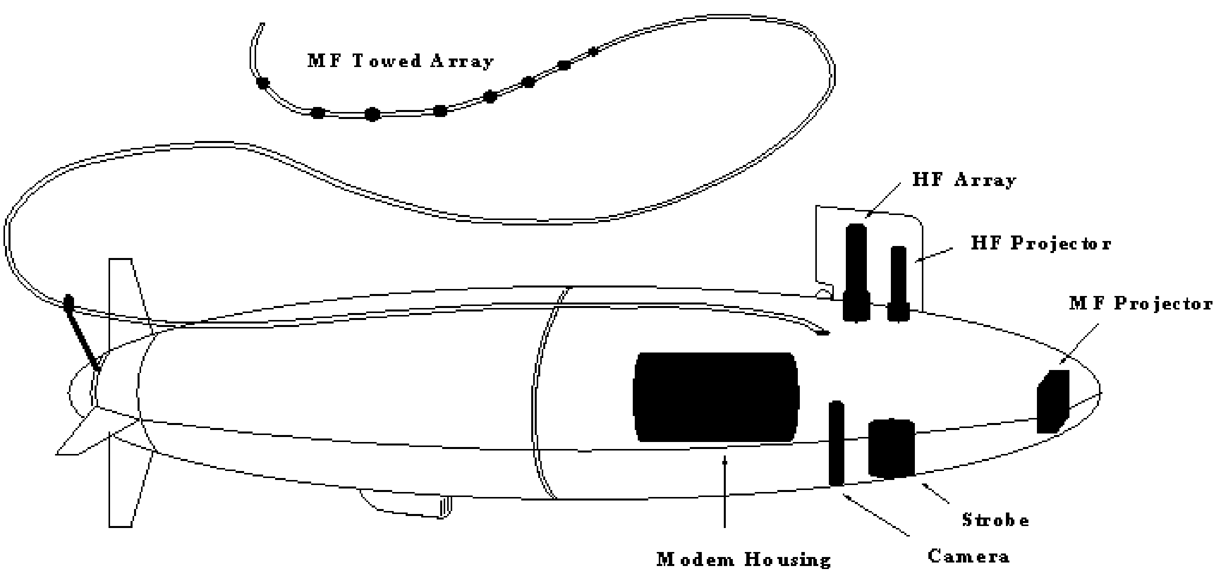
L. Freitag el al: 'A Bidriectional Coherent Acoustic Communications Systems for Underwater Vehicles,' *proceedings of the Oceans '98 Conference*, Nice, France, October '98.

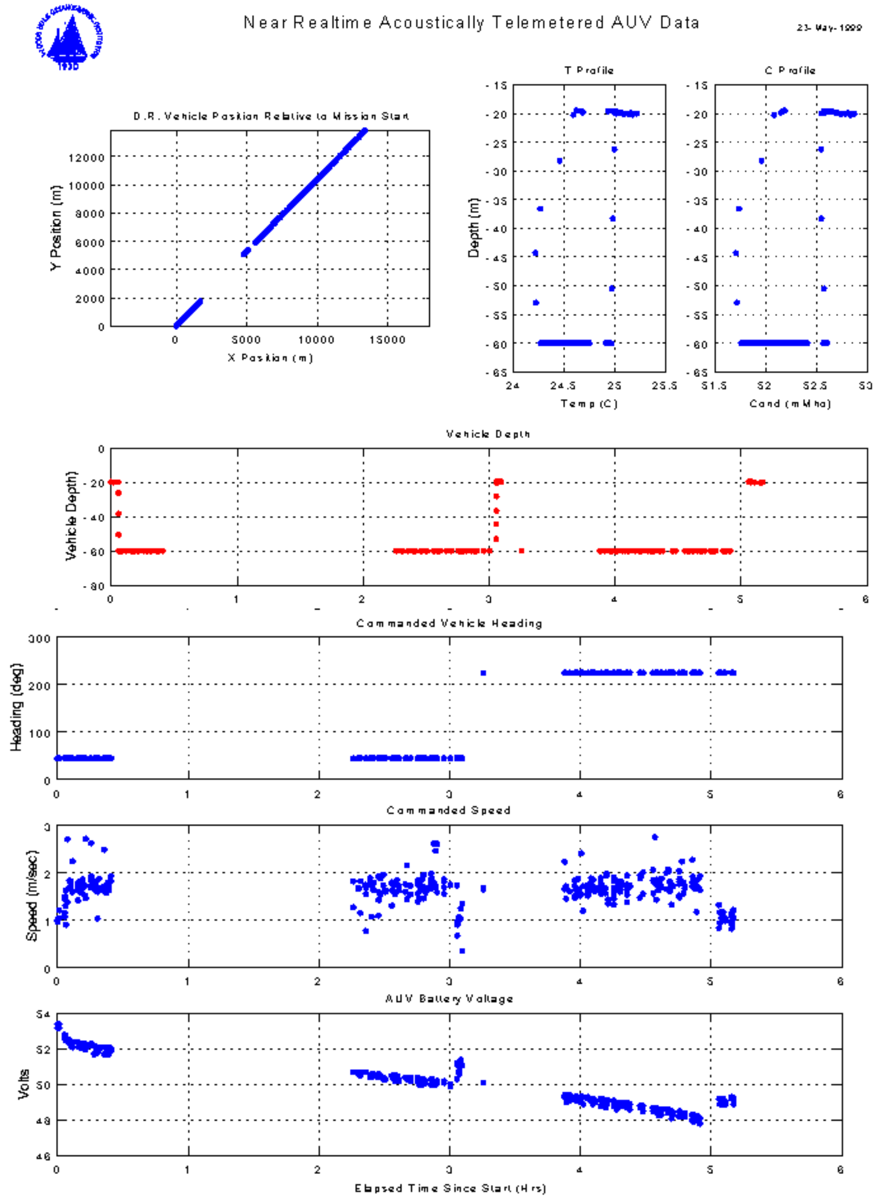


1. FAU Vehicle Self Noise Measurements





2. AUV ACOMMS Subsystems



3. In-Situ Vehicle Status via ACOMMS

4. Downloaded AUV Data via ACOMMS (each square is a transmitted packet)